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RISK ASSESSMENT OF THE HEALTH LIABILITIES
FROM EXPOSURE TO TOXIC METALS FOUND
IN THE COMPOSTED MATERIAL OF
AIR FORCE MUNICIPAL SOLID WASTE

THESIS

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AFIT/GEE/ENV/93S-10

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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THESIS

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Captain, USAF

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Approved for public release; distribution unlimited

Preface

This thesis would not have been possible without the assistance and support of people both inside and outside the Air Force Institute of Technology (AFIT). I would like to thank Capt Jim Aldrich for helping me to solidify the content and scope of the thesis research. I am also gratefully appreciative of the assistance given by Lt Col Mike Shelley who enabled me to find the sources I needed to conduct the risk assessment. It was also because of Lt Col Shelley's risk assessment class during the fall quarter that gave me the idea for this thesis in the first place. Another heartfelt thanks goes to Dr. Bleckman. If it were not for the few conversations that I had with him, I would have missed determining the whole baseline for the assessment. Thank you Dr. Bleckman.

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Part of my support base throughout this research came from a group of students at a local church. It was this youth group and the others on the youth staff that allowed me the ability to blow off the steam and energy that I needed to get rid of in order to sit down and do the work that was required to complete this project.

Another part of my support base came from the family that I brought with me on this adventure. To Sara my wife, who put up with the late nights and very little quality times, thank you for your patience and mercy. To Kathryn my daughter, who knows that "Daddy needs to work on his thesis so we can go to Alaska", thank you for all the study breaks that you made me take.

But most of all, I must give God the glory for the work that was achieved in these past 15 months. He kept me focused on what was important and He was the foundation on which all of my support stands. It was His words from the Apostle Paul to the Christians at Phillipi that got me through everything, "I can do all things through Christ who gives me strength" (Phillipians 4:13).

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Abstract

This thesis assesses the risk of the health liabilities from exposure to toxic metals found in the composted material of Air Force municipal solid waste (MSW). The goal is to determine the probability that the composted MSW could be a health hazard if it were used as a soil amendment. The research limited the assessment of the exposure risk to heavy metals found in raw MSW and its resulting compost.

The thesis uses reviews of present literature to examine the food and soil ingestion exposure pathways. These pathways are assessed using the heavy metal concentrations found in MSW compost and the soil-plant partition coefficients of vegetables grown in soil mixed with sewage sludge or soil irrigated with sewage sludge leachate.

The recommendation resulting from this research is that the Air Force should not use MSW composting as part of its future solid waste management plan. This alternative to landfilling contains a chronic health risk that is greater than the Environmental Protection Agency's guideline. If the Air Force would use MSW composting in the future, it may endanger Air Force personnel and others who use the compost created from Air Force MSW.

A RISK ASSESSMENT OF THE HEALTH LIABILITIES FROM EXPOSURE TO TOXIC METALS FOUND IN THE COMPOSTED MATERIAL OF AIR FORCE MUNICIPAL SOLID WASTE

I. Introduction

"Images of the garbage barge from Islip, New York wandering from port to port in search of a place to dispose of its load flooded the media during the summer of 1987. The sight so captured the public's attention that it became a topic of Johnny Carson's monologues" (Simmons, 1990:323). This is a very graphic example of the growing problem of disposing of the world's municipal solid waste (MSW). The most common and widely accepted way to dispose of nonhazardous MSW is to place it in landfills. However, not only are landfills becoming environmental hazards, but the number of active landfills is decreasing annually as shown in Figure 1.

The decreasing number of active landfills would not add to the problem, if new landfills could be sited. However,

> The ideal site for a sanitary landfill must meet many requirements. It should conform to the land-use plan of the area, have public approval, be reasonable in cost, adequate in area, and easily accessible, not pollute groundwater or the surrounding land, be protected from uncontrolled methane generation, and have a sufficient supply of earth cover. (Lipták, 1991:29)

Trying to find a site that can support all these requirements is a very difficult task. The public approval requirement is one of the more difficult requirements to meet. This is because of a syndrome commonly known as the "not-in-my-backyard" or

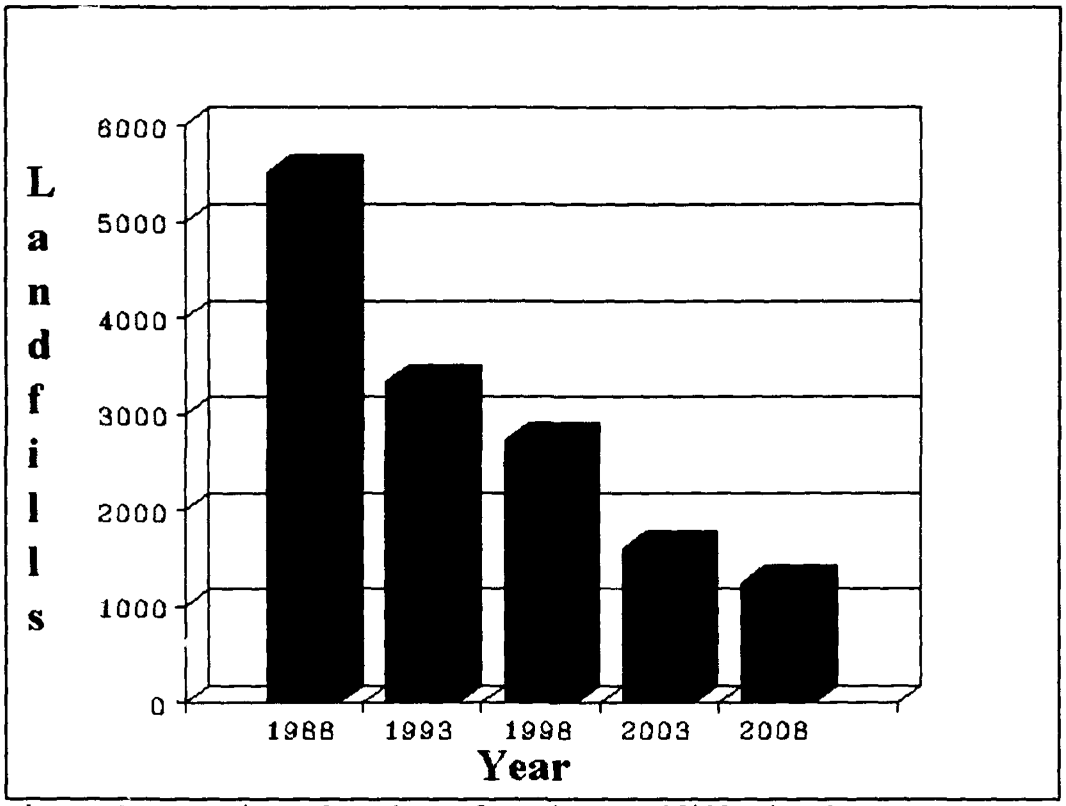

Figure 1. Estimated Number of Active Landfills in the Future ([US Congress, Office of Technology Assessment, 1989:273] taken from [EPA, 1988a])

NIMBY syndrome; landfill siting is a non-issue, as long as it is in someone else's neighborhood.

Increasingly restrictive requirements are not limited to new landfills. Current sanitary or MSW landfills are beginning to look less and less like the local 'dump' and beginning to look more and more like a hazardous waste landfill. Sanitary landfills once had trash simply tossed in and compacted every day. No concern was given to what was disposed of, how it was discarded, or if debris escaped into the surrounding landscape. Once they were full, they were capped and covered with soil. Today's sanitary landfills must be covered daily with six inches of soil and compacted to prevent debris from being blown around and to minimize the leaching of liquids. They must also be surrounded by monitoring wells to detect the leaching of any potentially harmful chemicals from the site. Because of these increased precautions, the only difference between sanitary landfills and hazardous waste landfills is a double layered impermeable lining at the bottom of the landfill.

Despite the increased precautions in new and existing MSW landfills, they are still becoming environmental hazards. This is due to the exemption from regulation of household wastes in the Resource Conservation and Recovery Act (RCRA). RCRA regulates the transportation, handling and disposal of municipal solid waste and hazardous waste. When it was written, however, RCRA excluded certain forms of waste from regulation. One form that was excluded was household waste (Case, 1992:411; 40 CFR § 261.4(b)). Household waste was exempted because people realized that it would be impossible to regulate every household in the nation. Therefore, items such as pesticides, cleaning agents and paint products are only regulated on an industrial level, even though these same products are found in almost every private home in the United States. This has resulted in the regulation of the disposal of hazardous wastes from industry, while the same substances are still deposited into the local sanitary landfill by private consumers.

The potential environmental and economic impact of RCRA's exemption of household wastes is evidenced by municipal governments which may begin paying for the cleanup of MSW landfills. In an article entitled, "Ye Olde Town Dump: Municipal Liability Under CERCLA," Barry Klayman writes of two district court judges who have made rulings regarding municipalities and their possible liability for the generation of MSW. In the case of B.F. Goodrich vs. Murtha, he writes:

> The court noted that Congress was aware of RCRA's household waste exclusion and could have excluded household waste from CERCLA liability but did not do so. The court held that CERCLA's definition of hazardous substances is very broad and not dependent on the source of the waste. If MSW, including household waste, contains a hazardous substance as defined in CERCLA and there is a release or threatened release of the substance at a facility, the municipality which arranged for the disposal of the waste may be liable under CERCLA regardless of the substance's origin. (Klayman, 1991:38)

Because of these court decisions, municipal governments are taking a stronger interest in what goes into the local landfill. Legislation is already in place restricting municipal waste haulers from open-dumping. Public and legal restrictions are also in place stating what landfills can and cannot accept. The stronger interest will cause already existing restrictions to become more restrictive. This tightening of restrictions will increase the tipping fees levied on the municipal waste hauler. Municipal waste haulers will also see higher costs in their industry resulting from having to separate the trash they collect from the consumer. The separation will be required because of the increased restrictions placed on the landfills. Municipal waste haulers, in turn, will reflect their increased tipping fees and other costs on the consumer through higher collection prices.

With the most common form of disposal becoming more expensive and less available, the Air Force must find an alternative to landfilling its municipal solid waste. The three most common alternatives to landfilling are incineration, recycling, and composting.

In order to be considered as an alternative for the Air Force, the alternative must be economically feasible and pose, at most, only a minimal threat to the environment and any exposed population. A minimal threat is a threat that is determined, through a risk assessment, to cause a carcinogenic risk or a chronic hazardous risk that is less than the acceptable risk standards set forth by the Environmental Protection Agency. A carcinogenic risk is a risk that will increase an organism's chances of contracting cancer during its lifetime. A chronic hazardous risk is a risk that an organism will suffer some adverse affect from being exposed to a threat during its lifetime.

II. Alternatives

Introduction

The three most commonly recognized alternatives to landfilling MSW are incineration, recycling, and composting. There are negative and positive aspects to each of these disposal methods which need to be discussed.

Incineration

In the book, Municipal Waste Disposal in the 1990s, Béla Lipták espouses the incineration process as the waste disposal method of the future. He does, however, give strong evidence of the amount of public opposition that must be overcome in order to use this method. In his words,

> The landfill-incinerator transition is similar to the oil-to-nuclear transition in that both require public acceptance. Opponents of the incineration point to the health hazard, the noise and odor, the increase in truck traffic, and the potential for air, land, and water pollution. (Lipták, 1991:87)

The idea of potential air pollution is reinforced by Rogoff in his article entitled, "Trends in Waste-to-Energy Industry." Rogoff focuses on the by-products of incineration that pollute the air. These by-products are: "Dust containing trace amounts of lead, cadmium, and mercury; acid gases such as sulfur oxides, hydrochloric acid and; hydrofluoric acid; nitrogen oxides; and organic emissions, including dioxins and furans" (Rogoff, 1992:61-62).

On top of public opposition and hazardous by-products, there are the exorbitant initial costs involved with constructing an incinerator. For example, Lipták describes an "average" incinerator as one that can serve a population of 500,000 and burn up to 1,000 tons of MSW per day. The cost for this "average" incinerator is estimated at $125 million for 1991 (Lipták, 1991:92). This high cost is the result of trying to control the potentially hazardous air emissions stated above. Lipták goes on to say that because of increasing air pollution restrictions, the cost can only increase (Lipták, 1991:92).

In addition to these disadvantages, there is the problem of the resulting incinerator ash residue disposal. According to Lipták, because of the heavy metal and dioxin content, incinerator fly-ash *will be banned from sanitary landfills in the near* future. "It does not seem feasible to dispose of such quantities of ash in hazardous-waste landfills, and it has not been proved that it is safe to dispose of it in regular landfills" (Lipták, 1991:96).

There are a lot of negative aspects to the incineration process at the present time. However, there is a positive side to incineration. Incinerators could be used in Air Force coal fired power plants to produce energy. This would be done by replacing some of the fossil fuel furnaces that are in use at present time with MSW incinerators. This replacement would reduce the Air Force's dependence on fossil fuels which are currently in short supply (Rogoff, 1992:62). By lowering the Air Force's dependence on fossil fuels, the Air Force would save money.

Money would be saved in several other areas as well. By burning both fossil fuels and MSW, the Air Force would not have to buy the large amount of fossil fuels that it used to purchase before an MSW incinerator was in operation. As for the

MSW, since the Air Force already owns it, the Air Force would not have to pay for this portion of its fuel stream. In turn, by burning Air Force MSW before it is taken to the landfill, the Air Force would save money on its waste hauling contracts. This savings would be the result of a much smaller volume of MSW that would actually leave the base.

Recycling

Recycling has already been started in local communities throughout the country. The initial incentive for recycling, on the part of the consumer, was financial. "Newspaper and aluminum can drives by churches and scout troops were common and buy-back centers provided individuals and groups with places to take their recyclables and redeem them for cash" (Kimball, 1992:5). Paper, glass, and aluminum were measured by the pound. Aluminum and glass were also measured by the bottle and can in some states. As Americans realized that landfills were being filled up with "biodegradable" material that could not biodegrade, they began to believe that recycling was the answer to the waste problem (Kimball, 1992:5).

However, recycling started before end use markets were created for the items being recycled. This massive recycling effort has created warehouses full of recycled materials that have been collected but can not be used. This stockpile has depressed the market prices of the materials. These depressed prices cause private consumers to become disinterested in recycling. They also cause an ever decreasing profit margin for municipal waste haulers, making it more expensive to collect these materials.

However, the sanitation companies have kept their programs running because legislation has been enacted to make recycling mandatory.

In order keep their programs running, municipal waste haulers have increased collection prices and have attempted to make recycling easier for the consumer. In many communities throughout the country, consumers no longer have to take recyclable materials to a central collection point in order for them to be recycled. Sanitation companies have distributed recycling bins to customers for the purpose of collecting recyclable materials. However, until the present stockpile of recyclable materials is used up, "the current economics of recycling remain the same: The dollar cost of recycling far outweighs the dollar value of the recyclables. It may take up to five times the amount of money a recyclable product is worth to collect, process, and transport it to a buyer" (Kimball, 1992:12).

At present, industry is creating uses for recyclables. Many fast food corporations are using bags and sandwich wrappers that are made of recycled paper. Packaging on many consumer products is stating that it is made of recycled materials. Tires are being used to make asphalt. The list goes on.

So, overall, recycling could be a good alternative to landfilling the Air Force's municipal solid waste. However, not everything can be recycled. Waste which cannot be recycled must still be disposed of in some other manner. Some examples of things which cannot be recycled are old appliances, worn out carpeting, food waste, shoes, and disposable diapers.

Composting

According to Charles Cannon, executive vice president of the Solid Waste Composting Council, "As much as 60 percent of the nation's garbage could be composted, including disposable diapers, soiled paper wrappers and thrown-out food as well as grass, leaves and branches" (Arrandale, 1991:81). Béla Lipták, in his book, Municipal Waste Disposal in the 1990's, stated that today the United States generates over 180 million tons of waste per year. This is an increase of more than 80 percent since 1960. If this trend persists, the U.S. will be generating over 216 million tons of waste per year by the turn of the next century (Lipták, 1991:8-9). If the country was to begin composting its municipal solid waste (MSW), it could reduce the amount going to landfills in the next century to 86 million tons. This means that the country would be landfilling only forty percent of the amount of waste it landfilled back in 1960 in the next century.

Not only does composting use a large amount of the waste products within the MSW stream, but unlike recycling, it has a readily available market in the many agricultural industries, including the backyard gardener. One example of the marketability of the product is shown by Colonie, New York's composting venture. Colonie, New York, started composting yard wastes in April, 1989, and by late summer, the town had given approximately 800 tons of compost to local farmers. The following spring, local gardeners took all the finished compost before the end of May (Zarpas, 1990:43).

Another example of just how marketable the product is comes from Wright County, Minnesota. A proposed MSW composting facility projected an annual yield of 35,400 cubic yards. A survey of a 15 mile radius around the proposed site showed that the demand for the product would be 57,300 cubic yards (Selby and others, 1989:57).

The main problem with composting MSW revolves around the Resource Conservation and Recovery Act (RCRA). Because of its exemption of household wastes, anything can be picked up by the municipal waste haulers, including old pesticide containers, cleansing agents, paint product residues and other potentially hazardous materials. These materials can be tossed into the garbage with no regard as to how they are packaged. This leads to the potential contamination of the compostable portion of MSW.

In response to this contamination, the Minnesota Pollution Control agency (MPCA) defined discrete finished compost classes: Class I and II. A Class I compost has "unrestricted distribution, while the distribution of a Class II product would be controlled by MPCA regulations" (Selby and others, 1989:56). These standards were set up based upon the metal concentration and the amount of inert materials in the finished compost. The compost product maximum average allowable contaminant concentrations are shown in Table 2.1.

Table 2.1
Class I Compost Product Maximum Average Allowable Contaminant Concentrations

Contaminant	Concentration (ppm, dry weight basis)
PCB	1
Cadmium	10
Chromium	1000
Copper	500
Lead	500
Mercury	5
Nickel	100
Zinc	1000

(Selby and others, 1989:56)

Another set of compost metal concentration standards that has recently come to light are the standards set forth by Environmental Protection Agency (EPA). Although these standards are for biosolids or domestic sewage sludge, the metal concentration limitations provided for land application of biosolids allow these standards to be compared to the MPCA standards for MSW compost. They can also be compared because both are soil amendments that contain metal concentrations which may pose a risk to an exposed population.

Like the MPCA standards, the EPA biosolids standards are broken into two categories for land application. The first set of standards are for "bulk biosolids applied to lawns and home gardens" (WEF, 1993:59). This set of standards is also known as the "high quality" pollutant concentration limits (WEF, 1993:58). The metal concentration limits for this application are shown in Table 2.2. The second set of standards are for "bulk biosolids applied to agricultural and non-agricultural land (for example, forest, public contact sites, and reclamation sites)" (WEF, 1993:59). The set of standards used for this application are known as the "ceiling concentration limits" (WEF, 1993:58). It is the ceiling concentration limits that need to be met for the biosolids to be qualified for land application. The metal concentration limits for land application are also shown in Table 2.2.

Table 2.2
Land Application Pollutant Limits

	"High Quality" Pollutant Concentration Limits	Ceiling Concentration Limits
Arsenic	41	75
Cadmium	39	85
Chromium	1200	3000
Copper	1500	4300
Lead	300	840
Mercury	17	57
Molybdenum	18	75
Nickel	420	420
Selenium	36	100
Zinc	2800	7500

(WEF, 1993:58)

The Air Force, as a leader in the environmental arena, must examine the limits set by the MPCA and the EPA to determine if either set of standards should be adopted by the Air Force if the Air Force decides to use the composting of MSW as part of its solid waste management plan in the future.

Conclusion

These three alternatives all involve many of the same materials. Paper, for instance, can be burned, recycled, or composted. Therefore, economic considerations and future liabilities need to be examined.

Incineration has high front end costs because of air emission controls and liabilities that may exist in the future if these controls happen to break down. Not only do the front end costs tend to be high, but every time an incinerator would be added to a base, a new point source for air emissions is added to the base air emissions inventory. In order to add the new source, the existing air permit would have to be modified or a new one written to include this point source. Finally, this point source would have to be monitored by the local regulatory agency who could fine the base if the incinerator would be found exceeding its permit. These problems could be alleviated if incineration is eliminated from consideration.

The remaining alternatives, recycling and composting, could be combined to eliminate a very large percentage of MSW from entering the landfill. However, some of the items that can be recycled can also be composted. The problem with recycling, as stated above, is the lack of end use markets that can utilize the recycled materials. This has left stockpiles of recycled materials just waiting for those markets to be created. The Air Force would benefit more if it were to compost its municipal solid waste, because of the already existing end use markets.

The only concern that remains is the possible contamination of the compostable portion of the MSW stream. Current collection methods by sanitation companies allow for household hazardous waste to be mixed with the portion of MSW that is compostable.

This study will investigate and determine if the toxic heavy metal concentrations in MSW compost are above or below the EPA's risk standard. If the heavy metal content, as determined by this study, does not result in a greater risk than the EPA's standard, then this study will determine if the standards for Class I MSW compost, as determined by the MPCA, should be adopted by the Air Force.

III. Methodology

Introduction

The purpose of this research was to determine if the possible health liabilities from exposure to composted Air Force municipal solid waste (AFMSW) would preclude the Air Force from composting municipal solid waste (MSW) as part of its future solid waste disposal management plan. To accomplish this purpose, certain investigative questions had to be answered. These questions included determining if the compostable fraction of the municipal solid waste stream contained harmful contaminants, identifying the concentrations of those harmful contaminants in the raw compostable portion of MSW, determining the concentrations, if any, of the harmful contaminants in the composted MSW, determining the bioavailability of the harmful contaminants in the composted MSW, identifying potential human exposure pathways, finding the increased potential for exposure to these harmful contaminants via the exposure pathways identified, and comparing the risks of the increased potential exposures to EPA standards.

Definition of Harmful Contaminants

The review of harmful contaminants in this study centered on heavy metals. Unlike volatile organic chemicals (VOCs), metals could be easily followed through the composting process. The metals could be followed easily because they could not break down into a more elemental form. Most VOCs, on the other hand, had a tendency to break down during the composting process along with the MSW.

The heavy metals that were examined in this study were cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and zinc (Zn). These metals were chosen as the study progressed for two reasons: their concentrations in MSW and their known health effects to populations exposed to them.

Metals in the Municipal Solid Waste Stream

It was assumed, for this study, that the contents of AFMSW were similar to a private community's MSW. Based upon this assumption, a literature review was conducted in order to identify if any of the metals listed above would be found in MSW. The review identified the sources and concentrations of heavy metals in the MSW stream. The review of the literature was also used to determine if these metals could be found in the compostable fraction of MSW.

The sample that was taken from this literature review determined the statistical average, the upper and lower 95 percent confidence intervals, and the standard deviation of the metal concentrations found in MSW. The 95 percent confidence interval determined if there was a possibility of getting raw MSW that did not contain prohibitive concentrations of heavy metal contaminants.

Because of the results of the statistical analysis of the metal concentrations found in MSW, a second literature review was conducted to determine the metal concentrations in MSW compost. This literature review centered around the metals studied in the first literature search. A sample of the heavy metal contaminants found in MSW compost was taken from the literature and a statistical analysis was conducted on the sample. Again the analysis looked at the average, the upper and lower 95 percent confidence intervals, and the standard deviation of the metal concentrations.

Background Metal Concentrations in Soil

To begin the risk assessment, the metal concentrations in MSW compost were compared to the background metal concentrations that are presently in the soil. The purpose of this comparison was to establish a baseline for the risk assessment. By knowing the background concentrations of metals in the soil, the investigation would show whether or not the addition of AFMSW compost to the soil would be contaminating the soil. If the concentration of heavy metals in AFMSW was higher than the background concentration in the soil, then the compost would be contaminating the soil and possibly exposing users of this product to an unnecessary risk. If the concentration of heavy metals in AFMSW was lower than the background concentration in the soil, then the question would become the following: does the combination of heavy metals in the soil and heavy metals in the compost expose users of this product to an unnecessary risk? In either case, the risk assessment would continue from this point to determine if the metals in soil and AFMSW compost are available for a plant or animal to absorb.

Bioavailability

A literature search was conducted to determine if heavy metals from AFMSW in the soil were available to an organism. For this investigation, the literature search emphasized experiments studying the effects of metals on the growing of backyard type vegetables, such as lettuce, beans, radishes, and onions. Studies such as these were much more applicable to the present research as compared to studies that examined the effects of metals on the growing of commercial crops such as wheat, soybeans, and corn. In addition, bioaccumulation of metals in the plants was a very important part of the review because the increased risk of exposure. Bioaccumulation would increase exposure not because of an increase in the metal concentrations in the soil or MSW, but because of the accumulation of metals in the backyard garden crops over the growing season.

Risk Assessment

To calculate perceived risk, the exposed populations and the methods of exposure had to be identified. This study was interested in the Military Family Housing (MFH) residents and others that would use AFMSW compost in their backyard gardens. The potential pathways of exposure in this case were the handling of the compost, inhalation of the dust from the compost and actual ingestion of the compost itself or a vegetable that was grown in the compost amended soil. These potential pathways were considered for both adults and children as applicable.

Once the pathways were determined, the analytes to be tested for were reviewed to determine if they were known carcinogens. A substance is determined carcinogenic through a series of assessments. One of these assessments is a Dose-Response assessment. This assessment assists in determining the increased risk of cancer for each unit increase in the dose of the suspected substance. Through regression analysis, a line is 'fitted' to the data. The slope of this line is known as the slope factor or potency factor. This factor is used to help determine the increased risk of contracting cancer due to exposure to the substance in question. If a series of substances was being examined through a particular pathway, then the individual risks from each of the chemicals are summed across that pathway and compared to what the Food and Drug Administration (FDA) and the Environmental Protection Agency have determined to be a reasonable risk.

A reasonable risk, as determined by the FDA and EPA, is 1.0E-6 excess cancer incidences per lifetime. This means that a person's chance of getting cancer during his or her lifetime is greater than one in a million. If the risk was less than 1.0E-6, then this means that a person's chance of getting cancer during his or her lifetime was less than one in a million. The FDA and EPA use this value to determine if an exposure is 'safe enough.'

If the analytes were not carcinogens, they still could be hazardous to the public in certain specified quantities over extended periods of time. This type of risk is known as a chronic non-carcinogenic risk. The metals that were in this category had known reference doses (RfD) for each of the three pathways. A RfD is a dose that can be taken on a daily basis without any harmful side effects to the person taking the metal at this concentration. For a chronic exposure, the hazard quotient was calculated for each metal for each exposed population group in each exposure pathway. The hazard quotient is the Chronic Daily Intake (CDI) divided by the RfD. The CDI is determined by multiplying intake frequencies, dose concentrations, and time of exposure and dividing the product of these values by the average body weight and the time over which the exposure is averaged for the population under study. These hazard quotients were summed to determine the total pathway hazard index. In summary, if the total pathway hazard index was below 1.0, then the pathway was considered safe according to EPA guidelines. If the total pathway hazard index was equal to or greater than 1.0, then the pathway was not considered safe according to EPA standards.

Conclusion

The metals in this study are not known carcinogens if taken in through the ingestion pathway. However, some of the metals, cadmium in particular, are known to be carcinogens if they enter the body through the inhalation pathway. A literature search revealed that, in the case of pure metals, the inhalation and dermal absorption pathways are insignificant in comparison to the ingestion pathway. Therefore, a carcinogenic study was determined to be unnecessary for this investigation. However, the chronic exposure still had to be examined.

The results of this investigation will determine if the Air Force can safely compost its municipal solid waste and distribute it to the base populace without the threat of contaminating the environment or adversely affecting the population that uses the compost product.

IV. Data Collection

Introduction

Municipal solid waste (MSW) consists of a wide variety of products that people no longer need or use, such as paper products (i.e. newsprint, computer paper, glossy magazine paper); cardboard and paperboard; soft and hard plastics; wood products; leather and rubber; food waste; yard waste; and noncombustible materials (Tillman, 1991:225-226).

Along with this seemingly nonhazardous waste, potentially hazardous waste products are also thrown out. A potentially hazardous waste product contains toxic substances. Waste products that contain toxic substances include, among other things, paint, batteries, some plastics, pesticides, and cleaning and drain-cleaning agents (Lipták, 1991:327).

Heavy metals such as cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and zinc (Zn) can be found in a variety of products that people dispose of every day. J. A. Ryan described just how common cadmium is in the sanitary waste stream when he presented his paper, "Cadmium: Utilization and Environmental Implication" at a conference in 1978. Even though his paper detailed the uses of cadmium in industry, the products that use cadmium in their processes are commonly used in homes throughout America. Ryan stated,

> Cadmium is used extensively in industry processes such as electroplating; and as pigments in paint, plastic and ink; as stabilizers in plastics; alloys; and for Ni-Cd batteries. Minor uses include electrical

contact production, curing of rubber, fungicides, and in solid state systems. (Ryan, 1978:269)

Products such as paint, plastic, ink, and Ni-Cd batteries are used by consumers on a daily basis, allowing the cadmium that industry uses to be discarded in the local sanitary landfill.

Sources of Metals in MSW

Thousands of basements and garages are cleaned out annually across America. It is during these cleaning 'frenzies' that people dispose of old paint, pesticides, herbicides, and other toxic substances that they no longer desire. Even Military Family Housing (MFH) residents are not exempt from this practice. Many dispose of the unused touch-up paint and pesticides that they no longer need and which are not returnable to the self-help store.

In the MSW stream, car batteries are a particular waste of concern. "It is estimated that 28 million car batteries are landfilled or incinerated every year" (Lipták, 1991:327). With this amount of car batteries being landfilled on an annual basis, 260,000 tons of lead contained in the batteries is also being landfilled (Lipták, 1991:327). Even though this is a problem at the present time, lead from car batteries can be eliminated from the present study because car batteries can be separated from the compostable portion of MSW because of their easily distinguishable size and weight.

Household batteries, on the other hand, are not as easy to separate from the compostable portion of the waste stream. Household batteries may not appear to pose a particularly serious problem, but Debi Kimball described just how large a problem these batteries are in the MSW stream.

> Although household batteries compose only about 0.005 percent by weight of the U.S. waste stream, they account for over 50 percent of the mercury and cadmium (both toxic metals) found in our trash. (Kimball, 1992:63)

The recycling of household batteries has been virtually nonexistent. Some small-scale recycling of household batteries is being accomplished with the button type batteries which are used to power digital watches and other small electronic equipment. Industry is beginning to recycle this type of battery because they can easily recover the mercury and silver in them (Kimball, 1992:63). However, there are numerous other types of household batteries that are not being recycled. "This category includes the following types of batteries: alkaline, carbon-zinc, nickel-cadmium, zinc-air, mercuricoxide, silver oxide, and lithium" (Kimball, 1992:62). Household batteries that are cracked or broken in pieces by sanitation trucks or compactors or rusted and corroded can leak their contents on to the compostable fraction of MSW long before current separation methods are employed at the composting plant.

Just like household batteries, plastics contain a number of heavy metals. These metals are used to stabilize the plastic: Cd, Cr, Pb, and Zn (Lipták, 1991:320). Even though some plastic is being recycled by many communities, there are still many sources of plastic in the MSW stream. These plastic sources that are not recycled may or may not contain heavy metals as stabilizers.

In many instances today, plastic packaging is known as biodegradable plastic. Biodegradable plastic is supposed to break down upon prolonged exposure to sunlight or ultraviolet rays. At present, composting floors normally have a roof but no walls, which allows sunlight to contribute to the composting process. If this biodegradable plastic uses heavy metals as stabilizers and is mixed with the compostable fraction of MSW, the plastic can break down into its constituent parts and contaminate the compost.

Another waste product that can contribute metals to the waste stream is paint. There has been a recent movement in the United States to remove old paint from buildings because it may contain lead. This movement started to prevent small children from consuming the old paint as it chips from the walls, ceilings, and exterior portions of old homes and other buildings. Another source of lead contaminated paint is from the process of refinishing furniture. Many homeowners take both of these tasks upon themselves. When the paint is stripped off, consumers simply bag it with their other trash and place it on the curbside for the sanitation company to haul away for disposal. These paint chips are small enough that they can be indistinguishable from the compostable fraction of MSW if they are mixed with it. However, this is a only a small portion of the problem.

Another source of paint contamination in the waste stream is from old paint cans. No one ever uses every last drop of paint they buy. Normally a small amount is left over after the work is done and a person will store this in case the work needs a touch up later. Usually the paint can will sit around for a number of years and the person will finally dispose of this unused portion during a garage or basement cleaning exercise. This paint may or may not contain metals in the pigment, but it can still be disposed of with other trash and have the potential to leak on to the compostable portion of the waste stream.

Metal Concentrations in MSW

The contamination of the compostable fraction of MSW is not limited to what can leak on to it or what can be mixed with it. Heavy metals can also be found directly in the compostable fraction of the MSW stream. Table 4.1 is a portion of a full spectral chemical analysis that was accomplished for the study, "Leachate and Gas From Municipal Solid Waste Landfill Simulators."

Table 4.1
Refuse Chemical Analysis
(mg/kg)

Component	Paper	Garden	Metal	Glass	Food	Plastic Rubber Leather	Fines	Ash Rock Dirt	Diapers	Wood	Composite
Cd	0.36	NA	20.90	2.70	NA	NA	4.20	4.50	0.25	1.60	2.40
Cr	8.20	1.10	15.30	1.10	1.30	2.00	13.10	10.10	1.10	1.10	10.70
Ni	15.70	15.70	115.0	19.00	12.5	32.00	33.20	10.10	3.36	27.0	10.10
Pb	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	15.00
Zn	50.00	106.00	175.0	9.75	59.0	118.00	322.0	181.0	343.00	59.4	127.00

(Walsh and others, 1981:71)

The MSW that was analyzed was a fresh sample from the Cincinnati, Ohio, area. The chart shows that heavy metals are not limited to the examples shown in this study: batteries, plastics, and paints, but are spread throughout the full spectrum of the municipal solid waste stream.

Table 4.2 shows the lower 95 percent confidence limit, the mean, the upper 95 percent confidence limit, and the standard deviation for heavy metal concentrations from ten samples of MSW. These samples are assumed to be typical of MSW across the nation. The data for the individual samples can be found in

Table 4.2
Descriptive Statistics for Metal Concentrations in MSW
(mg/kg)

	Cd	Cr	Ni	Pb	Zn
Low 95% CL	0.00	0.00	0.00	1.21	0.00
Mean	4.21	275.31	440.75	95.58	1921.10
Upper 95% CL	16.55	565.69	1102.10	253.81	4242.10
Std Dev	8.49	519.77	1127.34	133.27	3943.38

Appendix A. Take note of the lower 95 percent confidence limits for Cd, Cr, Ni, and Zn. Statistix, a statistical analysis computer package, originally returned a negative value for the lower 95 percent confidence limit. The negative concentration on this confidence limit indicates that MSW has a possibility of being free from metal contamination.

Metal Concentrations in Compost

Table 4.3 is the result of 26 MSW compost samples that were analyzed for heavy metals. These samples are from different studies than the studies that were used to determine the metal content in MSW. The table shows a reduction in the concentration of all metals except for Pb, which has increased by almost 46 percent between the MSW samples and the compost samples. According to Dr. Aldrich, the increase in the Pb concentration of the compost sample could be from atmospheric exposure. This atmospheric exposure may have resulted from past fuel emissions that contained Pb, causing free Pb in the environment which can be adsorbed by sources that may never have contained Pb previously (Aldrich, 1993:Interview). The reduction in the metal concentrations between MSW and composted MSW range from almost 50 percent for Zn to a 19 percent reduction for Ni. Data for Table 4.3 can be found in Appendix B.

Table 4.3
Descriptive Statistics for Metal Concentrations in MSW Compost
(mg/kg)

	Cd	Cr	Ni	Pb	Zn
Low 95% CL	1.79	29.92	29.13	132.57	498.86
Mean	2.75	66.42	49.01	238.29	717.12
Upper 95% CL	3.71	102.92	68.89	344.01	935.37
Std Dev	2.39	90.36	49.22	261.73	540.36

The reduction in the metal concentration between MSW and its composted form is a result of metals adsorbing to leachate that leaches from the compost piles. The leachate results from attempting to create an efficient and effective composting environment. In order for the composting process to be efficient and effective, the piles of MSW must have a certain moisture content. This moisture content eventually creates a leachate which trickles out of the piles and carries some of the metals that are adsorbed to it (Diaz and others, 1978:583). To determine if the metals remaining in MSW compost could pose a potential problem, baseline heavy metal concentrations need to be examined. Therefore, the concentrations of metals in the soil will be examined to determine the baseline, and then those concentrations will be compared to the concentrations found in the MSW compost.

Baseline Metal Concentrations

The book, Geobotany and Biogeochemistry in Mineral Exploration, by R. R. Brooks, examined heavy metal soil concentrations in 1972. Table 4.4 gives the results of that examination along with the mean concentration of the metals in MSW compost from Table 4.3.

Table 4.4
Comparison of Heavy Metal Background Concentration and MSW Compost Concentration
(mg/kg)

	Cd	Cr	Ni	Pb	Zn
Soil Concentration	0.50	200.00	40.00	10.00	50.00
Compost Concentration	2.75	66.42	49.01	238.29	717.12

(Brooks, 1972:295)

According to Brooks, the average concentration in the soil is, for the most part, significantly less than the concentrations in MSW compost. This result is supported by a study published in the June 1993 issue of The Journal of Environmental Quality.

The study, conducted by Holmgren, Meyer, Chaney, and Daniels, divided the types of soil into two different categories: Histosols, which are highly saturated organic soils, and Mineral Soils, which include all other soil types. The geometric mean concentrations for the metals under study, except for Cr which was not examined (N.E.), are shown in Table 4.5.

Table 4.5
Geometric Means for Selected Soil Elements in
U.S. Surface Soils
(mg/kg)

	Cd	Cr	Ni	Pb	Zn
Mineral Soils	0.155	N.E.	17.1	10.4	41.1
Histosols	0.606	N.E.	10.9	12.3	64.8

(Holmgren and others, 1993:339)

A comparison of the soil concentration values from Table 4.4 with those in Table 4.5 shows that all the baseline metal concentrations, except Nickel, given in Table 4.4 lie between the metal concentrations in Mineral Soil and the metal concentrations in Histosols. According to the results of both studies, in all cases, except for Cr which was not examined by Holmgren et al, the metal concentration in MSW compost is higher than the present soil baseline concentrations. From this information, the conclusion is drawn that a liability may exist if the metals contained in an MSW soil amendment are available to the plants and animals exposed to it. To determine whether or not this is possible, the bioavailability of the metals contained in an MSW soil amendment was investigated.

Bioavailability in Leaf Vegetables

This study is primarily interested in the availability of heavy metals to crops normally grown in the backyard garden because an Air Force installation has relatively few uses for a soil amendment. At present, the only uses for a soil amendment on a base are for landscaping around facilities in the contonement area, and as a fertilizer on the base golf course, if the base happens to have one. The only other use of a soil amendment on any installation would be in garden plots in the base MFH area. Of all these uses, the garden plots represent the highest possible risk for exposure.

From an examination of the literature dealing with the bioavailability of metals to plants, the most common vegetables studied were Romaine Lettuce, radishes, Swiss Chard, and spinach. Studies that use these plants to determine the soil-plant partition coefficient will be used to determine the availability of metals from the soil to the plants.

The study, "Plant Accumulation of Heavy Metals and Phytotoxicity Resulting from Utilization of Sewage Sludge and Sludge Composts on Cropland," was conducted by Chaney, Hundemann, Palmer, Small, White, and Decker in 1977. The results of this investigation were used for this risk assessment because of the time between the application of the sludge to the fields and the time when the experiments were conducted. Sewage sludge was applied to the experimental fields in 1973. However, actual experiments did not start in these fields until 1974. This allowed a year between the application of sludge and the first seeding for composting to occur. The assumption that the sewage sludge compost is similar to MSW compost comes from the EPA biosolid regulations that were discussed in Chapter 2. Since both MSW and domestic sewage sludge contain certain amounts of metals, sewage sludge compost was assumed equivalent to MSW compost in this study.

Swiss Chard and Romaine Lettuce were the crops used in the study. The results of one of their experiments showed that the absorption of Cd, Ni, and Zn by chard leaves is function of soil pH. Even though the backyard gardener is not overly concerned with the pH of the soil, the soil-plant partition coefficient as a function of soil pH is an issue to discuss for the present study.

Most soils that are used for gardening tend to be acidic in nature. Reasons for this include the type of vegetables grown in the garden and certain chemicals used on the garden soil. Tomatoes, which contain a mild acid, are grown in almost every garden in America. Most gardeners do not harvest all of the tomatoes grown, and so some are left to decay on the ground in the garden. The acid from the decomposing tomatoes seeps into the ground and lowers the pH of the surrounding soil. Chemicals, such as Muir-Acid, may also be added to the soil occasionally and can lower the soil pH.

This lowering of the soil pH becomes a concern for the present study because a metal is much more water soluble where the soil pH tends to be acidic. Therefore, the bioavailability of metals in a backyard garden could be greater than what is determined in this study because the gardener does not determine the actual pH of the garden soil.

The mean soil concentration, mean chard foliage concentration, and the soil-plant partition coefficient of chard foliage is shown in Table 4.6.

Table 4.6
Mean Soil, Chard, and Soil-Plant Partition Coefficient for Chard Leaves

	Cd	Ni	Zn
Mean Soil Concentration (mg/kg)	0.77	23.54	100.07
Mean Chard Concentration (mg/kg)	5.33	12.63	645.20
Soil-Plant Partition Coefficient (%)	1039.12	56.40	710.16

The data used to calculate these figures is presented in Appendix C in Figures C.1 to C.3. The mean soil concentration and mean chard foliage concentration were calculated by summing the 15 soil and plant samples in the respective analyte's table and taking the statistical average. The soil-plant partition coefficient was determined for each metal using the following equation:

$$PartitionCoefficient=\frac{\sum\frac{PlantConc(mg/kg)}{SoilConc(mg/kg)}}{15samples} \quad (1)$$

The results of these calculations show that the Cd and Zn absorbed by chard occurs independently of the concentrations of Cd and Zn in the soil. This finding indicates that Cd and Zn are not only available to plants, but that certain plants may accumulate these metals in their leaves during the growing season.

The bioaccumulation of Cd and Zn by plant foliage is supported by the results of a 1991 study entitled, "The Effects of Cadmium and Zinc Interactions on the

Accumulation and Tissue Distribution of Zinc and Cadmium in Lettuce and Spinach."

The study, which was conducted by McKenna, Chaney, and Williams, had three objectives:

> to examine in lettuce and spinach:
>
> (1) The effects of various levels of Cd in nutrient solution on the concentration of Zn in the leaves of plants grown at constant Zn level;
> (2) whether increasing concentrations of Zn in solution affected Cd concentrations in leaves of plants grown at constant Cd level; and
> (3) the changes in the distribution of Zn and Cd in roots and in old and young leaves as affected by the relative concentrations of Zn and Cd in the growth medium. (McKenna and others, 1991:113-114)

In meeting the third objective, McKenna et al. made some important discoveries about the bioavailability and bioaccumulation of Cd and Zn on Romaine Lettuce and spinach. Two of the four conclusions from his results are important to this study.

> (1) Cadmium accumulated more in old than young leaves independent of solution Cd level, whereas Zn followed that trend only at solution Zn levels equal to or greater than 3.16 μM; and
> (2) the concentrations of Cd and Zn in young leaves were related more closely to the relative concentrations of these metals in solution than for old leaves, especially for lettuce. (McKenna, 1991:118)

Assuming that the results of studies of plants grown in solution can be used to draw conclusions to plants grown in soil, point one indicates that the older a leaf is, the higher the amount of cadmium it can absorb. This supports the assumption that the bioaccumulation of cadmium in the foliage of crops grown in the backyard garden may be independent of the soil concentration. Point one, however, does not support the same assumption for Zn. According to the experimental results, Zn may have a threshold soil concentration. Below this concentration, Zn would not bioaccumulate in the foliage.

Point two of the study's results reinforces the bioaccumulation theories of Cd and Zn in both lettuce and spinach. According to these results, during the time a leaf is too young to be harvested, the concentration of Cd and Zn in the leaf remains close to the soil concentration. However, once the leaf is old enough to be harvested, it begins to accumulate Cd and Zn beyond their concentrations in the soil (McKenna and others, 1991:118).

Another result of the study conducted by Chaney et al. in 1977 showed that Cd did not just bioaccumulate during a single growing season, but persisted in the soil for several growing seasons in an available state that allowed it to be accumulated by plants grown in the soil. Sludge was applied to the fields in 1974, and crops were grown in 1974, 1975 and 1976. During these three years, Cd remained in the soil and also remained available to plants during the three successive growing seasons. The natural assumption is that even though the metals remain available to the plants, the concentrations in the plants will be less during the years after application. However, Chaney et al. switched crops from chard in 1974 and 1975 to tobacco in 1976. The tobacco, in most cases, absorbed higher concentrations of metals than either chard crop. The results from this study can be seen in Table C.1 in Appendix C.

Bioavailability in Root Vegetables

In the July-August 1980 issue of Compost Science and Land Utilization, Menser and Winant published the study, "Landfill Leachate as Nutrient for Vegetable Crops." Romaine Lettuce was examined as in the other two studies. However, Menser and Winant also studied radishes, which are root vegetables. The soil used in this study was irrigated with leachate collected from a sanitary landfill. Prior to planting, the average metal concentrations in the soil were Cd and Cr (0.5 ppm), Ni (2 ppm), Pb (6 ppm), and Zn (14 ppm) (Menser and Winant, 1980:50). The results of the study showed

> Toxic heavy metal concentrations in radishes were below the hazardous level for human consumption. Lead, Cr and Ni concentrations ranged from 1.5 to 5 ppm, whereas Cd levels were below 0.5 ppm. Tissues generally contained an average 6 ppm Cu and 42 ppm Zn. (Menser and Winant, 1980:50)

Even though the radishes did not have metal concentrations that were hazardous to humans, they did show evidence of bioaccumulation on the part of Cr, Ni, Pb, and Zn. The soil-plant partition coefficient of radishes as determined in this study is shown in Table 4.7.

Table 4.7
Mean Soil, Mean Radish, and Soil-Root Partition Coefficient for Roots

	Cd	Cr	Ni	Pb	Zn
Mean Soil Concentration (mg/kg)	0.15	3.25	3.25	3.25	14.00
Mean Radish Concentration (mg/kg)	0.50	3.00	3.00	3.00	42.00
Soil-Root Partition Coefficient (%)	333.33	83.33	83.33	83.33	300.00

McKenna et al. support the root bioaccumulation theory of Zn, but not the root bioaccumulation theory of Cd found by Menser and Winant. Their 1991 study also looked at the root concentrations of lettuce and spinach, along with the metal concentrations in the foliage of these two vegetables. According to their results, the roots of lettuce and spinach accumulated high concentrations of Zn but not Cd. Thus, Menser and Winant, supported by McKenna et al., found that Zn will accumulate in plant roots independent of the soil concentration, but will only accumulate in foliage if the soil concentration is above 0.207 ppm by volume.

The results of these two studies indicate that high concentrations of metals are absorbed by both leaves and roots. However, the leaf systems tend to accumulate a higher percentage of metals than the root systems. Even though the root system's metal concentrations were below the toxic level for humans in the Menser and Winant study, this does not prove that these metals will not accumulate in the human body causing an adverse effect.

Risk Assessment Overview

The three pathways that are easily accessible to the human population, with regard to the compost from municipal solid waste, are the dermal absorption pathway, the inhalation pathway, and the oral ingestion pathway. In the case of metal ions, the dermal absorption pathway is considered either insignificant when compared to the inhalation and oral ingestion routes, or metal ions are not considered as hazardous when compared to compounds containing them (USHHS, 1989:38; USHHS, 1989:21-24; USHHS, 1991:39-40; USHHS, 1989:40). Therefore, at present, there are no dermal absorption rates for heavy metal ions. Likewise, there are, at present, no inhalation reference doses for metal ions. The inhalation reference dose for Cd, Cr, and Ni has risk assessments that are under review by an EPA work group, while inhalation reference doses for Pb and Zn are currently not available (IRIS, 1993). Due to the unavailability of established RfD for the inhalation and dermal absorption pathways, only the oral ingestion pathway could be examined.

Oral ingestion can occur by one of two methods. The first method of ingestion is the eating of vegetables grown in soil that has been amended with a compost created from MSW. This method can be generalized over the adult population and their children who have backyard gardens. All of these individuals eat products from the garden at some time. The second method of oral ingestion is done primarily by children. This method is to directly ingest the soil amendment. Children between the ages of one year and six years have the greatest tendency to eat soil. However, children above the age of six years also have this tendency, but to a much lesser degree. All of these pathways were examined in this risk assessment.

Establishing the Reference Doses

Cadmium, Cr, Pb, Ni, and Zn are not established carcinogens with respect to the oral route of exposure. However, some of these analytes are suspected carcinogens. Because they are only suspected carcinogens, slope factors were not available for these analytes. However, under chronic exposure for the oral ingestion pathway, currently accepted oral reference doses were found for all analytes except for Pb. According to the Integrated Risk Information System (IRIS), Pb doses for all pathways are being reexamined at the present time. This investigation could have examined the risk of the oral exposure route for Pb using a previously accepted reference dose. However, using a previously accepted reference dose could make this study obsolete if the future reference dose for Pb was lower than the one used in this study. For this reason, Pb was not examined in this risk assessment.

The remaining analytes that were used in this risk assessment are shown in Table 4.8. Listed along with the oral reference dose are the uncertainty factors for that analyte's reference dose.

Table 4.8
Chronic Reference Doses for the Metals Under Investigation

Analyte	Dermal RfD (mg/kg)	Inhalation RfD (mg/kg)	Oral RfD (mg/kg)	Uncertainty Factor (unitless)
Cadmium	(1)	(2)	1.0e-03	10
Chromium (III)	(1)	(2)	1.0e+00	1000
Chromium (VI)	(1)	(2)	5.0e-03	500
Nickel	(1)	(2)	2.0e-02	300
Zinc	(1)	(2)	3.0e-01	10

(1) Not significant with respect to the Inhalation and Oral Routes
(2) RfDs are currently under review

The uncertainty factors for Cd and Zn show that toxicologists have a high certainty in the listed oral reference dose. Nickel and Cr(VI) carry a moderate uncertainty factor for the exposed population, while toxicologists are very uncertain of the listed reference dose for Cr(III). Because of the high uncertainty on the part of the oral reference dose for Cr(III) and the fact that the MSW compost studies and plant studies used in this research looked at total Cr concentrations, the risk assessment used the oral reference dose for Cr(VI). The oral reference dose for Cr(VI) was also used because it leads to a more conservative estimate of the risk.

In order to conduct the risk assessment, the chronic daily intake (CDI) had to be calculated for each of the analytes in question and then compared to the reference doses listed above. A separate equation is used for plant ingestion and direct soil ingestion. To calculate the plant ingestion CDI, the following equation was taken from exhibit 6-18 in the Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A): Interim Final (RAGS).

$$CDI = \frac{(CFxIRxFIxEFxED)}{(BWxAT)} \tag{2}$$

where

CDI = Chronic Daily Intake (mg/kg-day)

CF = Contaminant Concentration in Food (mg/kg)

IR = Ingestion Rate (kg/meal)

FI = Fraction Ingested from Contaminated Source (unitless)

EF = Exposure Frequency (meals/year)

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged - days)

The CDI equation for ingesting contaminated soil amendment will be calculated using the next equation which was also taken from RAGS.

$$CDI=\frac{(CSxIRxCFxFIxEFxED)}{(BWxAT)} \quad (3)$$

where

CDI = Chronic Daily Intake (mg/kg-day)

CS = Chemical Concentration in Soil (mg/kg)

IR = Ingestion Rate (mg soil/day)

CF = Correction Factor (10^{-6} kg/mg)

FI = Fraction Ingested from Contaminated Source (unitless)

EF = Exposure Frequency (days/year)

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged - days)

The variables used in Equations (2) and (3) will be discussed in the following two sections.

Exposure to Heavy Metals by Food Ingestion

For Equation (2), the contaminant concentration in food (CF) (mg/kg) was generalized to consider either leaf vegetables or root vegetables. The concentration in the leaves or roots was the product of the mean heavy metal concentration of MSW compost that was presented earlier in this study and the soil-plant partition coefficient of the leaves or roots as reported in this study. By determining the CF in this way, the assumption was made that the soil-plant partition coefficient of plants grown in MSW compost will be the same as the soil-plant partition coefficient of the plants grown in sewage sludge and sewage sludge leachate irrigated soils. The CF assumed that the availability of heavy metals in MSW compost is equivalent to the availability of the heavy metals in sewage sludge and its leachate. The mean concentration of the analytes in soil and the partition coefficients of foliage and roots are shown in Table 4.9 for convenience.

Table 4.9
Mean Heavy Metal Concentration in MSW Compost and the Soil-Plant Partition Coefficient of These Metals by Plant Foliage and Roots

	Cd	Cr	Ni	Zn
Mean MSW Compost Concentration (mg/kg)	2.75	66.42	49.01	717.12
Soil-Plant Partition Coefficient of Foliage (%)	1039.12		56.40	710.16
Soil-Plant Partition Coefficient of Roots (%)	333.33	83.33	83.33	300.00

The ingestion rates (IR) (kg/meal) for homegrown vegetables in this study came from the Exposure Factors Handbook, which was published by the Environmental Protection Agency (EPA). The handbook used the results from a study conducted by Pao et al. in 1982. This study presented a "3-day average intake of fruits and vegetables by consumers" (EPA, 1989a:2-16). Because the results are presented as a distribution, a large degree of uncertainty is introduced as the distribution rises beyond the fiftieth percentile. The handbook stated this uncertainty as follows:

> Obtaining a frequency distribution for all vegetables by summing the distributions for individual vegetables is not possible because the data represent the national average intake of each vegetable on any 1 day in the year. The sum of ingestion rates implies that the average individual's diet in 1 day included the average amount of all vegetables. In addition, similarly shaped distributions for each vegetable must be assumed. For example, the person whose consumption rate for tomatoes falls in the 90th percentile is also assumed to have a 90th percentile consumption rate for broccoli. While this assumption may be valid for consumption rates near the median, it introduces a large degree of uncertainty at the extremes of the distribution. (EPA, 1989a:2-16)

To try and minimize the degree of uncertainty in the risk assessment and still keep the analysis conservative, the ingestion rate values were taken from the fiftieth percentile of total raw vegetables. The distribution that resulted from Pao's study is located in Table C.2 in Appendix C. The values used for this risk assessment for leaf vegetables and root vegetables are 0.031 kg/meal and 0.017 kg/meal respectively.

The assumption was made that the fraction of homegrown vegetables that were ingested (FI) was 100 percent. This was considered a conservative estimate because most families with backyard gardens only eat a percentage of their vegetables from this source. According to the Exposure Factors Handbook, a worst case scenario might consider 40 percent of a family's daily vegetable intake would be from the garden (EPA, 1989a:2-17).

The exposure frequency (EF) (meals/year) for the analysis was assumed to be four months out of the year with an exposure duration (ED) of 30 years, and an averaging time (AT) of 30 years. The EF was used, understanding that root vegetables could be frozen to provide garden fresh vegetables throughout the year. The assumption in this assessment was that the root vegetables were not frozen but consumed as soon as they were mature. The ED in this assessment was considered conservative for two reasons. First, Air Force families move more often than the value of the exposure duration of 30 years. Second, garden policies are different between stations. For instance, some bases may not allow garden plots, and the families will not be exposed to contaminated vegetables during that tour. The assumption that families are exposed to contaminated food during the entire 30 years is, therefore, considered conservative.

Human body weights (BW) (kg) for this assessment were the standard weights used in most risk assessments. Studies have determined that a conservative assumption of an adult's body weight is 70 kilograms, while a conservative assumption of a child's body weight is 30 kilograms.

Exposure by Soil Ingestion

For Equation (3), the soil concentration (CS) for this pathway came from the mean concentration of metals in MSW compost as reported in this study and listed in Table 4.3.

The IR values for this pathway were taken from Exhibit 6-14 in RAGS. RAGS listed the EPA default values for ingestion rates of soil by children between one and six years of age and of children older than six years of age. For children between the ages of one and six, the default value is 200 mg/day. Children over the age of six are considered to ingest 100 mg/day. These values were considered conservative. The actual ingestion rates and thus the potential risk are probably much lower.

The rates for FI, ED, and AT were the same as those rates used in the CDI equation for food ingestion. Again, all of these values were considered conservative. FI was conservative because all of the soil ingested by a child would not come from the garden. If the compost was only applied to the garden, which may or may not be near the home, the actual FI could be extremely small. As for ED and AT, a military family normally does not stay at any one particular base for 30 years. Therefore, these values are considered conservative estimates of risk.

The EF for this equation was determined by RAGS to be 365 days per year. This value was considered to be a conservative estimate for risk because children would not get to play outdoors every day of the year. At least two weeks out of the year, they would be away from the backyard on vacation. At other times, weather or other events would keep children from playing outdoors in the backyard.

There were two BW values used for this calculation. The first value was for children between the ages of one year and six years. This value, listed in RAGS, was 16 kg. The value originated from the <u>Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments</u>, an EPA publication. The second value was the default value for children that was used in the food exposure pathway. This value was 30 kg.

Results

The results of the risk assessment calculations are shown in Table 4.10. The results are listed by pathway, and each pathway is broken down by population group. Within each population group, the Hazard Quotient is listed for each analyte. The last column lists the Pathway Hazard Index which is a summation of the Hazard Quotients within that respective pathway.

Table 4.10
Results of MSW Compost Risk Assessment
(Unitless)

	Hazard Quotient				Hazard Pathway Index
	Cadmium	Chromium	Nickel	Zinc	
		Food Pathway			
		Leaf Vegetables			
Adult Exposure	4.231	N.E.	0.205	2.513	6.948
Child Exposure	9.871	N.E.	0.477	5.863	16.212
		Root Vegetables			
Adult Exposure	0.744	0.899	0.166	0.582	2.391
Child Exposure	1.737	2.097	0.387	1.358	5.578
		Soil Pathway			
Child < or = 6 yrs	0.034	0.166	0.031	0.030	0.261
Child > 6 yrs	0.009	0.044	0.008	0.008	0.070

The results in Table 4.10 show that, for the food ingestion pathway, the perceived risk is greater than the EPA standard for a chronic exposure for both adults and children. Because of this perceived risk, composting of MSW and distribution of the compost by the Air Force may incur potential liabilities that are unacceptable. These liabilities revolve around the potential adverse effects from the metals accumulating in the bodies of Air Force personnel and others. There is also the possibility of lawsuits brought against the Air Force, should someone trace their medical problems to the compost created from Air Force MSW.

However, the soil ingestion pathway shows that MSW compost could be used in areas where plants grown in the soil amendment would not be consumed by humans. These areas may include the base golf course and landscaped areas throughout the base. However, another concern arises about animals eating the plants grown in AFMSW compost. Animals sometimes eat plants growing in the flower beds. According to the food ingestion pathway, this may also bring unacceptable liabilities to the Air Force because of the potential killing of animals that live around the installation. Therefore, the Air Force should not use composting as part of its Solid Waste Management Plan until these problems can be resolved.

V. Discussion, Conclusions and Recommendations

Introduction

The results of this investigation indicate that the Air Force should not use municipal solid waste (MSW) composting as part of its future Solid Waste Management Plan. This indication is from the concentration of metals found in MSW compost and the percentage of metals absorbed by plants, both in their roots and foliage.

Metal Concentrations in MSW Compost

A large portion of the sample data collected for determining the heavy metal concentrations in MSW compost was taken from actual MSW composting plants that are currently in operation in the United States. The rest of the sample data collected for determining the heavy metal concentrations in MSW compost was taken from the results of heavy metal concentration analyses done on pilot scale projects conducted in Canada.

A comparison of the Canadian concentrations and the American concentrations showed a consistently lower metals content in the compost from the Canadian facilities. The reason for this is not directly known, but it may have had something to do with the source separation methods of the compostable fraction between the two countries. Of the nine U.S. facilities that were surveyed, only one used some type of source separation. The other eight facilities "would be described as using a non-source-separated waste stream" (Taylor, 1991:68). The Canadian facilities were listed as composting "source-separated organics only" (Taylor, 1991:72). Source-separated organics are organics that are separated at the source, the consumer's home. This method of composting MSW may reduce many of the contaminant concentrations discussed in this study to a level that would allow a future risk assessment to return a positive result.

Percentage of Metals Absorbed by Roots

The percentage of heavy metals absorbed by plant roots seems to be dependent upon the amount of heavy metals that are available in the growth medium. One weakness of the risk assessment comes from using only one study to determine the bioavailability of metals to roots for this investigation. One other investigation was studied, but its absorption percentages were not entered into the soil-root partition coefficient calculations because the study was not representative of the scenario that was being studied. The second study examined plants grown in a growth solution and not in soil.

The data that was chosen for the risk assessment came from the results of radishes grown in sewage sludge leachate irrigated soil. The data that was not incorporated into this study came from the results of lettuce and spinach grown in solutions spiked with Zn and Cd treatments (McKenna and others, 1991:114). The plants grown in solution had soil-root partition coefficients in the tens of thousands compared to the percentages used in the risk assessment. The disparity, from the different growth methods, brings up the question: what concentrations of heavy metals in MSW compost are bioavailable compared to the total concentrations of heavy metals in MSW compost? This question will be discussed in more detail later.

Another weakness in this part of the risk assessment comes from the soil-root partition coefficient calculations. The percentage of metal absorption by roots was calculated using the mean root concentration and the mean soil concentration. This method, calculating the mean of the dependent variable from the means of the independent variables, returns a lower dependent mean than if the dependent values were figured separately from each independent data point, and then averaged. However, this weakness was unavoidable due to the presentation of the results of the study. The study from which the data was taken only reported the mean soil concentrations and the mean root concentrations without regard to the individual samples.

Percentage of Metals Absorbed by Foliage

One weakness with the metal absorption data for leaf vegetables was that all of the data was from one sample study. A second sample study was examined, but the absorption data was discarded because the study was not representative of the scenario that was being studied.

Available Metals Versus Total Metals

In assembling the data for the soil-plant partition coefficient calculations in both roots and foliage, it was noted that plants grown in solution absorbed a much higher percentage of metals than did those plants grown in metal contaminated soil. In both cases, the percentage uptake from plants grown in solutions treated with Cd and Zn was in the tens of thousands to hundreds of thousands (McKenna and others, 1991:117). This indicates that follow on work from this study could include determining the fraction of the total heavy metals in compost that is bioavailable and finding ways to bind or remove this available fraction without causing other environmental problems.

Comparison of Study Results to MPCA and EPA Standards

Table 5.1 shows the comparison of the metal concentrations used in this risk assessment, the maximum average allowable contaminant concentrations for Class I compost according the Minnesota Pollution Control Association (MPCA), and the "high quality" pollutant concentration limits from the sewage sludge standards of the Environmental Protection Agency (EPA).

Table 5.1
Comparison of MPCA Heavy Metal Standards and Mean Concentrations Found in This Study
(mg/kg)

	Cd	Cr	Ni	Pb	Zn
EPA Standards	39	1200	420	300	2800
MPCA Standards	10	1000	100	500	1000
Mean Concentration	2.75	66.42	49.01	238.29	717.12

The comparison shows that the EPA and MPCA standards are possibly in error. However, the comparison could also show that the assumptions in this study are too conservative. At the present time, it is recommended that the Air Force should not adopt either the EPA standards or the MPCA standards as concentration limits on metals in any type of compost. Research that could be generated from this risk assessment would include examining the thought and studies that went into determining the EPA and the MPCA standards for the concentration limits on the respective composts and comparing these to the work done in this study.

Conclusion

This risk assessment recommends that the Air Force should not adopt a solid waste management plan that would include composting MSW at the present time. However, given the conservative assumptions used in this risk assessment, there is a possibility that the Air Force could conduct MSW composting without endangering the end users. To make this possible, the Air Force would need to employ source-separation methods in order to separate the most common contaminants of MSW such as batteries, paints, and plastics. As stated earlier in the chapter, research could be conducted to determine just how safe source-separated MSW compost is compared to the non-source-separated MSW compost.

Also, further research needs to be conducted on the actual absorption percentages in roots and foliage of backyard vegetables. The research should also expand to look at different types of vegetables such as beans, peas, and tomatoes since these types of plants would probably have an absorption percentage that is different from leaves and roots.

Another recommendation from this study is to determine the percentage of available heavy metals in MSW compost and then examine the possibility of binding the available metals in MSW compost in an environmentally safe manner. If this solution could be found, then the compost could be used without exposing anyone to an unacceptable risk.

Appendix A. Sample Data for MSW Heavy Metal Concentrations

Table A.1
The Range of Trace Metals
in Municipal Solid Waste

Metal	Range of Concentration of Solid Waste (ppmw)
Cadmium (Cd)	0.05-25
Chromium (Cr)	3.0-375
Lead (Pb)	7.75-9.15
Nickel (Ni)	3.25-3,228
Zinc (Zn)	23-11,500

(Tillman, 1991:243)

Table A.2
Trace Metal Content in RDF Fuel at
Red Wing Minnesota (ppmw in fuel)

Metal	Low	High	Average
Cadmium	ND	3.8	0.9
Chromium	30.0	1,512	263.9
Lead	85.0	350	255.0
Nickel	35	137	100.5
Zinc	80	2,268	503.1

(Tillman, 1991:244)

Table A.3
Trace Metal Concentrations in Mixed Waste Paper Samples from the State of Washington
(ppmw in the fuel)

Metal	Mean	Minimum	Maximum
Cadmium	0.7	1.3	1.9
Chromium	6.48	0.7	11.4
Lead	7.5	0.7	49.5
Nickel	7.25	1	14
Zinc	149.2	8.5	837

(Tillman, 1991:247)

Appendix B. Sample Data for Metal Concentrations in MSW Compost

Table B.1
Test Results, Heavy Metals in MSW Compost
(slashes indicate more than one test)

U.S. MSW Facilities	Cadmium (ppm)	Chromium (ppm)	Lead (ppm)	Nickel (ppm)	Zinc (ppm)
Agripost	4.1	20.5	124	34	607
Sumter County	1.8	-	370	38	870
Delaware	2.8	-	323.7	132.6	952
St. Cloud	2.7	29.4	219.5	27.5	456.5
Lake of the Woods	3.4	15.6	56.3	12.1	317.8
Fillmore County	5.9/ 12.1	29.0/ 63	-	29.0/ 57	784.0/ 2078
Pennington County	2.7/ 2.8	16.6/ 16.8	301.5/ 320.5	21.0/ 20.2	559.2/ 589
Swift County	1.0/ 2	21.0/ 61	98.0/ 311	8.0/ 20	524.0/ 1338
Powell River	0.9/ 0.62 /0.38	13.0/ 15.82 /13	14.0/ 27.29 /34	7.0/ 8.58 /6.6	109.0/ 177.1/ 200
Guelph	0.56	8.07	37.47	6.81	135.55

(Taylor, 1991:76-77)

Table B.2
Concentration of Elements and Other Constituents in Composts Sampled Throughout the United States

Analyte	MSW (Parts per million (dry weight))				MSW + Yard Waste (Parts per million (dry weight))	
Cadmium	1.67	2.49	1.01	1.76	ND	3.26
Chromium	76.3	162	149	182	372	173
Lead	1312	406	146	267	308	342
Nickel	46.5	130	74.2	109	200	105
Zinc	667	2427	645	624	998	673

(Lisk and others, 1992:192-193)

Table B.3
Heavy Metals in MSW Compost from Operating Facilities
(mg/kg dry weight)

Analyte	Agrisoil	Fairgrove	Fillmore	St. Cloud	Sumter
Cadmium	4.1	3.4	2.9	2.2	5.0
Chromium	20.5	223	12.8	33.5	-
Lead	124	496	82.4	185	290
Nickel	34	77	15.1	28	27
Zinc	607	1008	329	396	580

(Walker and O'Donnell, 1991:66)

Appendix C. Percentage Uptake Tables

Table VI: Effect of Digested Sludge and Composted Digested Sludge Applied in 1973 on Cd in Soil and in Crops Grown in 1976 1/

Treatment	Mt/ha	9/76 2/ pH	Cd in Soil Total	DTPA	Cd in Crops Chard leaves	Corn grain
			- - - - mg Cd/kg dry matter - - - -			
Control	0	6.1	0.12	0.03	1.31i 3/	0.04f 3/
Sludge Low	40	5.1	0.40	0.22	8.57cd	0.37abc
"	80	5.3	0.77	0.39	13.5a	0.29bcd
"	160	5.1	1.23	0.65	12.2ab	0.45ab
"	240	4.5	2.10	0.99	10.6bc	0.52a
Sludge High	80	6.7	0.77	0.40	2.91gh	0.12def
"	160	6.8	1.56	0.67	2.31ghi	0.22cde
"	240	6.6	2.18	0.91	2.10hi	0.29bcd
Compost Low	40	5.2	0.18	0.10	4.53efgh	0.20cdef
"	80	5.3	0.29	0.14	6.22def	0.15def
"	160	4.8	0.38	0.25	5.55efg	0.26cd
"	240	5.0	0.51	0.29	6.91de	0.34bc
Compost High	80	6.5	0.21	0.12	1.06i	0.04f
"	160	7.0	0.37	0.18	1.04i	0.05ef
"	240	7.0	0.51	0.24	1.11i	0.07ef

1/ Chaney, Small, Palmer, Mullen, Simon, and Epstein; unpublished results.

2/ Elemental sulfur added to low pH plots to reach desired soil pH levels in April, 1976.

3/ Within column, values followed by the same letter are not significantly different at the 5% level according to the Duncan's Multiple Range Test

Figure C.1 Soil Cadmium Concentration Versus Chard Leaf Cadmium Concentration (Chaney and others, 1977:95).

Table IV: Effect of Digested Sludge and Composted Digested Sludge Aplied in 1973 on Ni in Soil and in Crops Grown in 1976 1/

Treatment	Mt/ha	9/76[2] pH	Ni in Soil Total	Ni in Soil DTPA	Ni in Crops Chard leaves	Ni in Crops Soybean grain
			- - - - mg Ni/kg dry matter - - - - -			
Control	0	6.1	5.7	0.4	1.0c[3]	3.9cd[3]
Sludge Low	40	5.1	12.9	0.8	5.7c	5.7cd
"	80	5.3	8.5	0.9	11.3c	8.2cd
"	160	5.1	13.3	1.6	9.2c	10.0c
"	240	4.5	10.1	2.0	10.0c	9.7c
Sludge High	80	6.7	8.3	0.4	0.9c	2.3d
"	160	6.8	11.4	0.6	0.9c	2.5d
"	240	6.6	13.6	0.7	0.9c	2.0d
Compost Low	40	5.2	25.8	2.5	28.8b	19.8b
"	80	5.3	22.9	3.7	39.7a	22.3b
"	160	4.8	44.0	8.5	40.9a	31.6a
"	240	5.0	54.5	9.0	33.5ab	30.8a
Compost High	80	6.5	23.7	1.3	2.2c	5.4cd
"	160	7.0	41.6	1.9	2.1c	6.9cd
"	240	7.0	56.8	2.5	2.3c	6.3cd

1/ Chaney, Small, Palmer, Mullen, Simon, and Epstein: unpublished results.

2/ Elemental sulfur added to low pH plots to reach desired soil pH levels in April, 1976.

3/ Within column, values followed by the same letter are not significantly different at the 5% level according to the Duncan's Multiple Range Test

Figure C.2 Soil Nickel Concentration Versus Chard Leaf Nickel Concentration (Chaney and others, 1977:95).

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Table V: Effect of Digested Sludge and Composted Digested Sludge Applied in 1973 on Zn in Soil and in Crops Grown in 1976 1/

Treatment	Mt/ha	9/76 2/ pH	Zn in Soil: Total	Zn in Soil: DTPA	Zn in Crops: Chard leaves	Zn in Crops: Soybean leaves
			- - - - mg Zn/kg dry matter - - - - -			
Control	0	6.1	24	1	76f 3/	51c 3/
Sludge Low	40	5.1	69	11	1240c	106c
"	80	5.3	91	28	2140a	237b
"	160	5.1	154	52	1530b	338a
"	240	4.5	216	85	1604b	296ab
Sludge High	80	6.7	99	17	276ef	64c
"	160	6.8	177	43	295ef	75c
"	240	6.6	242	64	247ef	76c
Compost Low	40	5.2	45	3	415def	64c
"	80	5.3	46	6	467de	76c
"	160	4.8	66	11	460de	112c
"	240	5.0	79	13	671d	102c
Compost High	80	6.5	47	3	81f	46c
"	160	7.0	63	7	92f	53c
"	240	7.0	83	10	84f	53c

1/ Chaney, Small, Palmer, Mullen, Simon, and Epstein; unpublished results.

2/ Elemental sulfur added to low pH plots to reach desired soil pH levels in April, 1976.

3/ Within column, values followed by the same letter are not significantly different at the 5% level according to the Duncan's Multiple Range Test.

Figure C.3 Soil Zinc Concentration Versus Chard Leaf Zinc Concentration (Chaney and others, 1977:95).

Table C.1
Effect of Sewage Sludges Applied in 1974 on Cd in Soils and Crops: 1974 to 1976

Treatment	Soil	Crops					
	Total	1974	1975				1976
	Cd	Chard	Chard	Orchard Grass	Soybean Grain	Romaine Lettuce	Tobacco
	(ppm)	(ppm dry weight)					
Control	0.04	0.75	0.5	0.19	0.12	0.57	2.5
B.P. Sludge	0.94	4.0	5.3	0.60	0.32	2.49	17.5
B.P. Compost	0.89	1.7	1.1	0.37	0.20	1.11	8.1
High Metal	0.32	2.0	1.4	0.30	0.20	1.68	4.9
Dried Sludge B	1.06	24.0	11.6	1.44	1.03	11.6	22.9
Dried Sludge A	1.94		17.9	5.04	1.77	26.4	43.7

(Chaney and others, 1977:96)

Table C.2
Average Daily Consumption of Total Vegetables, from Three-Day Dietary Recall at Specified Percentiles (g/day)

Food Category		% Home grown	Percentile 5.0	25.0	50.0	75.0	90.0	95.0	99.0	Avg.	Std Dev	% indiv using food in 3 days
Potatoes	Total		14.0	33.0	62.0	103.0	158.0	202.0	309.0	78.0	65.0	74.4
	Home grown	11.9	1.7	3.9	7.4	12.3	18.8	24.0	36.8			
Cabbage	Total		5.0	15.0	20.0	40.0	40.0	60.0	90.0	27.0	20.0	9.7
	Home grown	16.2	0.8	2.4	3.2	6.5	6.5	9.7	14.6			
Carrots	Total		1.0	5.0	17.0	22.0	41.0	51.0	96.0	18.0	19.0	5.0
	Home grown	15.9	0.2	0.8	2.7	3.5	6.5	8.1	15.3			
Cucumber	Total		3.0	12.0	23.0	47.0	79.0	105.0	220.0	37.0	45.0	5.6
	Home grown	39.5	1.2	4.7	9.1	18.6	31.2	41.5	86.9			
Lettuce	Total		3.0	13.0	31.0	54.0	90.0	113.0	186.0	40.0	39.0	50.7
	Home grown	4.2	0.1	0.5	1.3	2.3	3.8	4.7	7.8			
Mature Onions	Total		1.0	6.0	7.0	15.0	24.0	37.0	73.0	13.0	16.0	8.5
	Home grown	10.0	0.1	0.6	0.7	1.5	2.4	3.7	7.3			
Tomatoes	Total		10.0	20.0	30.0	60.0	91.0	123.0	205.0	44.0	42.0	27.8
	Home grown	48.7	4.9	9.7	14.6	29.2	44.3	59.9	99.8			

(EPA, 1989a:2-19)

Bibliography

Abrams, Donald R. and Timothy D. Brecheen. A Technical and Practical Study of Composting as a Solid Waste Management Alternative for the Air Force. MS thesis, AFIT/GEE/ENV/92S-1. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1992.

Aldrich, James A. Captain, PhD., Air Force Institute of Technology, Wright-Patterson AFB OH. Personal Interview. 6 July 1993.

Aleshi, B. A., W. H. Fuller, and M. V. Boyle. "Effect of Leachate Flow Rate on Metal Migration Through Soil," Journal of Environmental Quality, 9: 119-126 (January/March 1980).

Alloway, Brian J., Andrew P. Jackson, and Hilary Morgan. "The Accumulation of Cadmium by Vegetables Grown on Soils Contaminated From a Variety of Sources," The Science of the Total Environment, 91: 223-236 (February 1990).

Angle, J. S., M. A. Spiro, A. M. Heggo, M. El-Kherbawy, and R. L. Chaney. "Soil Microbial-Legume Interacts in Heavy Metal Contaminated at Palmerton, PA," University of Missouri/et al Trace Substances in Environmental Health 22nd Conference. 321-336. St. Louis, 23-26 May 1988.

Arrandale, Tom. "A Rotten Solution for Our Solid-Waste Woes," Governing, 4: 81 (April 1991).

Bolton, K. A. and L. J. Evans. "Elemental Composition and Speciation of Some Landfill Leachates With Particular Reference to Cadmium," Water, Air, and Soil Pollution, 60: 43-53 (November 1991).

Bond, Bruce E., Bingham Y. K. Pan, and R. M. Roberts. Characteristics and Size Reduction of Navy and Municipal Solid Waste. Port Hueneme CA: Naval Civil Engineering Laboratory, May 1987 (AD-A183 768).

Brooks, R. R., Geobotany and Biogeochemistry in Mineral Exploration, New York, NY: Harper and Row, 1972.

Caffrey, R. Patrick and Robert K. Ham. "The Role of Evaporation In Determining Leachate Production From Milled Refuse Landfills," Compost Science, 15: 11-15 (March/April 1974).

Case, David R. "Resource Conservation and Recovery Act," in Environmental Law Handbook, 11th Ed. Rockville MD: Government Institutes Inc., 1992.

Chaney, R. L., P. T. Hundemann, W. T. Palmer, R. J. Small, M. C. White, and A. M. Decker. "Plant Accumulation of Heavy Metals and Phytotoxicity Resulting from Utilization of Sewage Sludge and Sludge Composts on Cropland," Presented at National Conference on Composting of Municipal Residues and Sludges. 86-98 (23-25 August 1977).

Christensen, Thomas H. "Cadmium Soil Sorption at Low Concentrations. IV. Effect of Waste Leachates on Distribution Coefficients," Water, Air, and Soil Pollution, 26: 265-274 (November 1985).

-----. "Cadmium Soil Sorption at Low Concentrations. VII: Effect of Stable Solid Waste Leachate Complexes," Water, Air, & Soil Pollution, 44: 43-56 (March 1989).

Cohen, D. B., M. D. Webber, and D. N. Bryant. "Land application of Chemical Sewage Sludge - Lysimeter Studies," Proceedings Sludge Utilization and Disposal Seminar. 108-137. Toronto: Enviornmental Protection Service, 1978.

Cooper, Robert C. and Clarence G. Golueke. "Survival of Enteric Bacteria and Viruses in Compost and Its Leachate," Compost Science, 20: 29-35 (March/April 1979).

Diaz, Luis F. and G. J. Trezek. "Chemical Characteristics of Leachate from Refuse-Sludge Compost," Compost Science/Land Utilization, 20: 27-30 (May/June 1979).

-----, G. J. Trezek, and C. G. Golueke. "Leachate from Refuse-Sludge Compost," Proceedings of the First Annual Conference of Applied Research and Practice on Municipal and Industrial Waste. 559-584. Madison WI, 10-13 September 1978.

----- and Clarence G. Golueke. "Status of composting in the United States," Resource Recycling, 9: 40-74 (February 1990).

Environmental Protection Agency (EPA). 1988a. Report to Congress: Solid Waste disposal in the United States. Vol. II. EPA/530-SW-88-011B.

-----. 1988b. Solid Waste Disposal in the United States. Report to Congress. EPA/530-SW-88-011B.

-----. 1989a. Exposure Factors Handbook. Office of Health and Environmental Assessment. EPA/600/8-89/043.

-----. 1989b. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual. Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002.

-----. 1992. Health Effects Assessment Summary Tables. Annual FY 1992. Office of Research and Development. Office of Emergency and Remedial Response. OERR 9200.6303(92-1).

Epstein, Elliot and Jonathan I. Epstein. "Public Health Issues and Composting," Biocycle, 30: 50-53 (August 1989).

Friedman, Naomi. "Recycling: Five Communities that Do It Right," American City & County, 107: 34-42 (October 1992).

Gillis, Anna Maria. "Shrinking the Trash Heap," BioScience, 42: 90-93 (February 1992).

Giusquiani, Pier Lodovico, Giavanni Gigliotti, and Daniela Businelli. "Heavy Metals in the Environment, Mobility of Heavy Metals in Urban Wastes-Amended Soils," Journal of Environmental Quality, 21: 330-335 (July-September 1992).

Goldstein, Nora and Robert Spencer. "Solid Waste Composting in the United States," Biocycle, 31: 46-50 (November 1990).

Greco, James R. "Analyzing by Categories U.S. Urban Refuse," Solid Waste Management, 17: 60-62 (August 1974).

Harries, C. R., A. Scrivens, J. F. Rees, and R. Sleet. "Initiation of Methanogenesis in Municipal Solid Waste. 1. The Effect of Heavy Metals on the Initiation of Methanogenesis in MSW Leachate," Environmental Technology, 11: 1169-1175 (December 1990).

Hegstrom, Linda J. and Stephen D. West. "Heavy Metal Accumulation in Small Mammals following Sewage Sludge Application to Forests," Journal of Environmental Quality, 18: 345-349 (1989).

Hernando, S., M. C. Lobo, and A. Polo. "Effect of the Application of a Municipal Refuse Compost on the Physical and Chemical Properties of a Soil," The Science of the Total Environment, 81/82: 589-596 (June 1989).

Holmgren, G. G. S., M. W. Meyer, R. L. Chaney, and R. B. Daniels. "Cadmium, Lead, Zinc, Copper, and Nickel in Agricultural Soils of the United States of America," Journal of Environmental Quality, 22: 335-348 (April-June 1993).

"Is Your Trash Really Rottin'?" Science World, 46: 17 (20 April 1990).

James, Stephen C. "Metals in Municipal Landfill Leachate and Their Health Effects," American Journal of Public Health, 67: 429-432 (May 1977).

Kimball, Debi. Recycling in America: A Reference Handbook. Santa Barbara, CA: ABC-CLIO, 1992.

Klayman, Barry. "Ye Olde town Dump: Municipal Liability under CERCLA," American City & County, 106: 38-40 (April 1991).

Landreth, Robert E. and Jerome L. Mahloch. "Chemical Fixation of Wastes," Industrial Water Engineering, 14: 16-19 (July/August 1977).

Leita, Liviana and Maria De Nobili. "Heavy Metals in the Environment, Water-Soluble Fractions of Heavy Metals during Composting of Municipal Solid Waste," Journal of Environmental Quality, 20: 73-78 (January-March 1991).

Liptak, Bela G. Municipal Waste Disposal in the 1990s. Radnor, PA: Chilton Book Company, 1991.

Lisk, Donald J., Walter H. Gutenmann, Michael Rutzke, H. Thomas Kuntz, and G. James Doss. "Compostion of Toxicants and Other Constituents in Yard or Sludge Composts From the Same Community as a Function of Time-of-Waste-Collection," Archives of Environmental Contamination and Toxicology, 22: 380-383 (May 1992).

Lisk, Donald J., Walter H. Gutenmann, Michael Rutzke, H. Thomas Kuntz, and Gordon Chu. "Survey of Toxicants and Nutrients in Composted Waste Materials," Archives of Environmental Contamination and Toxicology, 22: 190-194 (February 1992).

Long, Janice. "Hazardous Waste Found in Household Garbage," Chemical and Engineering News, 65: 14-15 (12 October 1987).

McDermott, Brian F. Analysis of a Waste Minimization Program for Nonhazardous Solid Wastes Utilizing Source Reduction and Recycling Techniques and its Application to Air Force Installations. MS thesis, AFIT/GLM/DEV/91S-46. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1991 (AD-A246 705).

McKenna, Ilda Melo, Fufux L. Chaney and Frederick M. Williams. "The Effects of Cadmium and Zinc Interactions on the Accumulation and Tissue Distribution of Zinc and Cadmium in Lettuce and Spinach," Environmental Pollution, 79: 113-120 (1993).

Menser, H. A. and W. M. Winant. "Landfill Leachate as Nutrient Source for Vegetable Crops," Compost Science/Land Utilization, 21: 48-55 (July/August 1980).

Norstrom, James M., Charles E. Williams, and Paul A. Pabor. "Properties of Leachate from Construction/Demolition Waste Landfills," Proceedings of the Fourteenth Annual Madison Waste Conference. 357-366. University of Wisconsin-Madison: Department of Engineering Professional Development, 25-26 September 1991.

Raveh, Ariela and Yoram Avnimelech. "Leaching Of Pollutants from Sanitary Landfill Models," Journal WPCF, 51: 2705-2716 (November 1979).

Rice, Steven. "Waste Management: The Long View," Chemtech, 21: 543-546 (September 1991).

Richard, Tom and Matt Chadsey. "Environmental Impact of Yard Waste Composting," Biocycle, 31: 42-46 (April 1990).

Rogoff, Marc J. "Trends in Waste-to-Energy Industry," Engineering News Record, 228: E-61-E-63 (1992).

Rousseaux, P., A. Borges de Castilhos, P. Vermande, and J. Veron. "Determination of Trommel Meshes for Optimal Separation of Compostible Fraction of Solid Wastes from Florianopolis, SC, Brazil," Resources, Conservation and Recycling, 6: 217-229 (May 1992).

Ryan, J. A. "Cadmium: Utilization and Environmental Immplication," Proceedings of the First Annual Conference of Applied Research and Practice on Municipal and Industrial Waste. 269-285. Madison WI, 10-13 September 1978.

Sable, Ellen R. "Trace Metals in Combustible Municipal Solid Waste," Proceedings of 1990 National Waste Processing Conference, Fourteenth Biennial Conference. 229-233. New York: American Society of Mechanical Engineers, 1990.

Selby, Mark, Joe Carruth, and Brian Golob. "End Use Markets for MSW Compost," Biocycle, 30: 56-58 (November 1989).

Sims, J. T. and J. S. Kline. "Chemical Fractionation and Plant Uptake of Heavy Metals in Soils Amended with Co-Composted Sewage Sludge," Journal of Environmental Quality, 20: 387-395 (April-June 1991).

Simmons, Deborah A. and Ron Widmar. "Participation in Household Solid Waste Reduction Activities: The Need for Public Education," Journal of Environmental Systems, 19: 323-331 (1989-1990).

Taylor, Paul. "Heavy Metals Criteria for Compost," Resource Recycling, 10: 68-80 (September 1991).

Tillman, David A. The Combustion of Solid Fuels and Wastes. San Diego CA: Academic Press, 1991.

U.S. Health and Human Services. Toxicological Profile for Cadmium. ATSDR/TP-88/08, Contract No. 68-02-4228, Agency for Toxic Substances and Disease Registry, March 1989.

-----. Toxicological Profile for Chromium. ATSDR/TP-88/10, Contract No. 68-C8-0004, Agency for Toxic Substances and Disease Registry, July 1989.

-----. Toxicological Profile for Nickel (Draft). Contract No. 205-88-0608, Agency for Toxic Substances and Disease Registry, October 1991.

-----. Toxicological Profile for Zinc. ATSDR/TP-89/25, Contract No. 205-88-0608, Agency for Toxic Substances and Disease Registry, December 1989.

U.S. Congress, Office of Technology Assessment, Facing america's Trash: What Next for Municipal Solid Waste. OTA-0-424, Washington, D.C.: U.S. Government Printing Office, October 1989.

Walker, John M. and Michael J. O'Donnell. "Comparative Assessment of MSW Compost Characteristics," Biocycle, 32: 65-69 (August 1991).

Walsh, James J., Riley N. Kinman, and Janet I. Rickabaugh. "Leachate and Gas from Municipal Solid Waste Landfill Simulators," EPA 7th Annual Research Symposium. 1: 67-93 (16-18 March 1981).

WEF Residuals Management Committee. "Biosolids and the 503 Standards," Water Environment & Technology, 5: 56-62 (May 1993).

Zarpas, Stephanie. "Pay Dirt," The Conservationist, 45: 40-43 (September 1990).

Vita

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This thesis assess the risk of the health liabilities from exposure to toxic metals found in the composted material of Air Force municipal solid waste (MSW). goal is to determine the probability that the composted MSW could be a health haz[ard] if it were used as a soil amendment. The research limited the assessment of the exposure risk to heavy metals found in raw MSW and its resulting compost.

The thesis uses reviews of present literature to examine the food and soil ingestion exposure pathways. These pathways are assessed using the heavy metal concentrations found in MSW compost and the soil-plant partition coefficients of vegetables grown in soil mixed with sewage sludge or soil irrigated with sewage sludge or soil irrigated with sewage sludge leachate.

The recommendation resulting from this research is that the Air Force should n[ot] use MSW composting as part of its future solid waste management plan. This alternative to landfilling contains a chronic health risk that is greater than th[e] Environmental Protection Agency's guideline. If the Air Force would use MSW composting in the future, it may endanger Air Force personnel and others who use compost created from Air Force MSW.

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